HYDRODYNAMIC AND SALINITY ANALYSIS

of a
PROPOSED NAVIGATION CHANNEL

in the
ST. LUCIE ESTUARY

by

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South Florida Water Management District
Resource Planning Department
Water Resources Division

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EXECUTIVE SUMMARY

For some time Martin County, the City of Stuart, the Florida Department of Transportation (FDOT), and concerned citizens have been discussing alternatives to the current Roosevelt Bridge. The existing bridge crosses the St. Lucie Estuary just north of the City of Stuart, Florida, and provides a continuation of US Route 1. The bridge is a draw span which opens for boat traffic numerous times a day, resulting in considerable delays along US Route 1.

All parties are in agreement that something has to be done to the current situation to help relieve this traffic bottleneck. The Florida Department of Transportation's preferred alternative is a high level, fixed span bridge.

One other suggestion has been the construction of a low level causeway across the existing channel in combination with the construction of a tunnel with an overlying navigation channel to allow for unrestricted boat traffic above the road. In April, 1989, the South Florida Water Management District was requested by the Chairman of the Martin County Board of County Commissioners to assist in the evaluation of the proposed navigation channel.

This report documents a preliminary investigation on the influence that the proposed navigation channel would have on the hydrodynamics and salinity of the St. Lucie Estuary. This study is conducted through use of computer simulation to evaluate the effects that construction of a new navigation channel would cause in the current estuarine system. Simulation of hydrodynamics and salinity in the estuary is accomplished through the application of a numerical model. The St. Lucie Estuary Computer Model (SLECM) is a hydrodynamic / salinity computer model capable of simulating large-scale responses in discharge (flow), salinity, and tidal elevation (stage) throughout the St. Lucie Estuary under a variety of tidal and hydrologic conditions. The results of this study indicate that construction of the proposed navigation channel would minimally impact the flow patterns and not affect the salinity distributions of the St. Lucie Estuary.

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INTRODUCTION

For some time Martin County, the City of Stuart, the Florida Department of Transportation (FDOT), and concerned citizens have been discussing alternatives to the current Roosevelt Bridge. The existing bridge crosses the St. Lucie Estuary just north of the City of Stuart, Florida, and provides a continuation of US Route 1. The bridge is a draw span which opens for boat traffic numerous times a day, resulting in considerable delays along US Route 1.

All parties are in agreement that something has to be done to the current situation to help relieve this traffic bottleneck. The Florida Department of Transportation's preferred alternative is a high level, fixed span bridge.

One other suggestion has been the construction of a low level causeway across the existing channel in combination with the construction of a tunnel with an overlying navigation channel to allow for unrestricted boat traffic above the road. In April, 1989, the South Florida Water Management District was requested by the Chairman of the Martin County Board of County Commissioners to assist in the evaluation of the proposed navigation channel.

This report documents a hydrologic investigation on the potential influence that the proposed navigation channel would have on the hydrodynamics and salinity of the St. Lucie Estuary. The purpose of this study is to provide a preliminary evaluation of the effects that the establishment of a new navigational channel would have on the estuary. Simulation of hydrodynamics and salinity in the estuary is accomplished through the application of a numerical model. This model simulates large-scale responses in discharge (flow), salinity, and tidal elevation (stage) throughout the estuary.

A. Study Area

The St. Lucie Estuary is located on the southeast coast of Florida, in the vicinity of the city of Stuart. Figure 1 is a map of the St. Lucie River Estuary and the major geographic features in the vicinity of the estuary. The system consists of three major sections; the North Fork, South Fork, and Middle Estuary. The North Fork originates north of Port St. Lucie at the confluence of Five-Mile Creek and Ten-Mile Creek in St. Lucie County. The South Fork begins in Martin County and flows north with the bifurcation of the St. Lucie Canal (C-44) and Old South Fork occurring about eight miles southwest of Stuart. Waters of the North Fork and the South Fork join at Stuart, six miles from the coast, and then flow eastward through the Middle Estuary. The Middle Estuary extends east from this confluence for three miles before turning south into the Indian River Lagoon directly west of the St. Lucie Inlet.

The existing Roosevelt Bridge connects Stuart with Speedy Point (Figure 1). Replacement of this drawbridge with a causeway, tunnel, and navigation channel would result in structural modification of the flow regime in the present estuarine system. Figure 2 illustrates the conceptual design of the proposed Roosevelt Bridge Causeway through plan and section views of the causeway, tunnel, and navigation channel. Construction of the tunnel and associated waterway across the peninsula would provide an additional channel for the movement of water in the St. Lucie estuary.

B. Numerical Simulation

The St. Lucie Estuary Computer Model (SLECM) is specifically developed for simulating hydrodynamics and salinity in the St. Lucie Estuary (SFWMD Technical Publication 87-1: Modeling of Hydrodynamics and Salinity in the St. Lucie Estuary; Morris 1987). This analytic tool provides the means necessary to numerically simulate hypothetical conditions in the estuary. This capability provides the opportunity to evaluate the effects of proposed hydraulic structural modification in the St. Lucie Estuary.

ANALYSIS:
METHODS AND PROCEDURES

Computer models can address a variety of practical hydrologic problems to appraise hydraulic project-design alternatives and to support environmental impact assessments. The St. Lucie Estuary Computer Model (SLECM) is a comprehensive, one-dimensional estuary model based on a numeric solution of the complete set of hydrodynamic equations. The SLECM is a simulation program capable of predicting water surface elevation, mean velocity, discharge, and salt concentration (salinity) as a function of location and time in an estuary.

A. St. Lucie Estuary Computer Model (SLECM)

The SLECM is a fully dynamic, deterministic hydrodynamic and mass transport model that employs a link-node approximation and a half-step / full-step solution technique. The model consists of a main program containing the comprehensive set of unsteady flow equations and eighteen external routines structured to accommodate a diversity of open-channel configurations and hydrologic conditions. Input files consist of a set-up file, digitized estuary geometry, and five program databases. Animated graphical output is incorporated into the model as an efficient means to provide engineers and water managers with flow information compiled and condensed into easily comprehensible formats. These features help transform the model into a comprehensive tool for practical use in simulating discharge and salinity distributions in time and space for a variety of hydrological and tidal conditions.

B. Estuary Geometry

The volume of water in an estuary is defined by the irregularities of the shoreline, the topography of the bed, and artificial boundaries drawn across tributaries. The representation of this water volume in the model is described as a network of nodes connected by links, or junctions connected by channels. A 'network' is defined as a system of open channels multiply connected in a configuration that permits more than one flow path to exist between certain locations in the system. The nodes identify branches, inflow or outflow locations, and significant stage measurement points to be properly oriented according to the geography of the estuary. The links, or channels, represent the mean flow characteristics between the nodes.

The existing St. Lucie Estuary is represented in the SLECM as a network of sixty-three nodes connected by sixty-two links in a one dimensional (horizontal) arrangement with one tidal boundary and time-varying inflows/outflows located at five nodes. The river-estuarine system is schematized as shown in Figure 3. This numerical description of the physical system and specification of the flow regime is read into the main program from the digitized estuary geometry input file.

Modification of the 63 node / 62 link network to evaluate the proposed navigation channel is accomplished by establishing channel 63. Figure 4 illustrates Channel 63 (Link E), which is 3529 feet in length (distance between nodes 14 and 18), 80 feet in width, and 17 feet in depth (dimensions of navigation channel; section view, Figure 2). Thus, the geometry input file for the proposed causeway and tunnel with overlying navigation channel is composed of sixty-three channels that join at sixty-three node locations; 63 node / 63 link network.

C. Simulation Conditions

Hydrologic investigations should analyze the entire range of expected conditions in order to provide a comprehensive evaluation of different hydraulic project designs. Tidal influence is the predominant force in most situations that occur in an estuary. However, the effects of precipitation, evaporation, regulatory discharges, and groundwater seepage in the estuary can be significant. The model is used to compare the effects of different inflow and/or outflow sequences in the estuary. The inflows and outflows consist of direct rainfall, point and non-point runoff, evaporation, and time-constant ground water seepage. Since the SLECM simulations follow a sequence of inflows, many of which are dependent on antecedent rainfall, the model may be described as tidal and rainfall driven.

The basic assumption in predictive simulations is that rainfall patterns will be consistent with the historical record. The limitation in using historical rainfall for simulations is that the patterns of daily values are random, such that the daily distribution of rainfall occurring in the historic record is not very likely to be similar to the rainfall that will actually occur in the future. However, it is reasonable to assume that averaged over sufficient time, the total inflow calculated from actual rainfall, from both low and high rainfall periods, will reflect the range of expected inflows.

Five drainage basins conduct runoff to the St. Lucie Estuary: North Fork basin, C-24 basin, C-23 basin, C-44 basin, and South Fork basin. Fifty-one years (1936 through 1986) of tabulated precipitation record exists for these drainage basins. Ranking the annual basins precipitation results in the year 1982 ranked first (1/51) with 81.19 inches of rainfall and the year 1981 ranked fiftieth (50/51) with 36.99 inches of rainfall. Thus, simulations using precipitation data from September to December 1982 (27.57 inches of rainfall) would represent a "wet" period. Similarly, simulations including precipitation data from July 1981 (4.33 inches of rainfall) would represent a "dry" period.

The SLECM is configured to operate for specified dates and times which is convenient in using historical rainfall, inflow, and salinity conditions. Re-creation of historical events in the estuary is accomplished through historical input files for the measured water surface conditions at the tidal boundary, rainfall records, structure inflows, and salinities. Since this preliminary investigation is concerned with evaluating the entire range of expected conditions, examination of the database indicates that these conditions occur in 1981, 1982, and 1987. This range of conditions includes a drought period (1981), a period of high rainfall (1982), and normal conditions (1987). Additionally, the normal condition includes pulsed releases of water at structure S-80 which is part of an on-going experimental flood control program for Lake Okeechobee.

D. Geographic Analysis

The St. Lucie Estuary Computer Model (SLECM) is capable of simulating hydrodynamic and salinity conditions in the entire St. Lucie Estuary. The objective of this study is to evaluate potential environmental impact and appraise changes to the estuary resulting from the proposed navigation channel. Model simulations can provide an insight into the tidal-cycle variability in flow and salinity concentration as influenced by freshwater inflow conditions, varying natural runoff, meteorological effects, tidal fluctuations, and human activities.

Discharge is the one specific characteristic that depicts the transport properties and flushing capacity of an estuarine system. Examination of discharge at locations A, B, C, D, and E in Figure 4 (SLECM links 14, 15, 16, 48 and 63, respectively), provides an indication of flow characteristics in the vicinity of the existing Roosevelt Bridge, alternative causeway, and site of the proposed navigation channel.

The St. Lucie Estuary is an important habitat for marine species, and salinity distribution in the estuary has an important influence on this habitat. Examination of salinity at locations F, G, H, and I in Figure 4 (SLECM nodes 8, 18, 23, and 49, respectively), provides an indication of habitat conditions in the St. Lucie Estuary. These locations are dispersed throughout the estuary; location F (node 8) is situated in the Middle Estuary east of Roosevelt Bridge, location G (node 18) is found in the North Fork at the terminus of the proposed navigation channel, location H (node 23) is sited near the center of the North Fork, and location I (node 49) is positioned in the northern portion of the South Fork, just south of Roosevelt Bridge.

Tidal influence is the predominant force in most situations that occurs in an estuary. The location of the transition from one flow pattern and salinity to another varies primarily in response to changing tide. Examination of water surface elevation at locations J, K, L, and G in Figure 4 (SLECM nodes 14, 15, 16, and 18, respectively), provides an insight into tide cycle variation in the St. Lucie Estuary in the vicinity of the existing Roosevelt Bridge, alternative causeway, and site of the proposed navigation channel.

RESULTS AND DISCUSSION:
ESTUARINE HYDRODYNAMICS AND SALINITY

Flow in the St. Lucie Estuary is generally tidal with varying influences of freshwater sources. The flow patterns and salinity distribution vary primarily in response to changing tide, varying natural runoff, meteorological conditions, and flood control discharges. The objectives of this study are to evaluate potential environmental impact and appraise hydraulic variation in the estuary.

A. Discharge

Discharge indicates the transport properties and flushing capacity of an estuarine system and is expressed in units of cubic feet per second (cfs). Mean velocity is calculated by dividing the discharge through a channel by its corresponding cross-sectional area and is expressed in units of feet per second (fps). Table 1 and Table 2 present the results from simulations in the existing Roosevelt Bridge Channel, proposed Causeway, and proposed Navigation Channel.

TABLE 1: MAXIMUM DISCHARGE

	"dry" 1981	"wet" 1982	"normal" 1987
Existing Roosevelt Bridge Channel	15,000 cfs	33,000 cfs	14,500 cfs
Proposed Causeway	15,000 cfs	32,000 cfs	14,500 cfs
Proposed Navigation Channel	850 cfs	1500 cfs	650 cfs

Examination of Table 1 indicates that the "wet" period represents the maximum simulated discharges in the estuary. Figures 5 through 9 are time history graphs of simulations for discharge from the high rainfall period (September 5 to December 1, 1982). These graphs plot the range of expected discharges.

Figure 5 is a re-creation of the discharges that occurred at locations A, B, C, and D in the estuary (Figure 4). Figure 6 is a simulation of the discharges that would have occurred with the proposed causeway and navigation channel at locations A, B,

TABLE 2: MAXIMUM MEAN VELOCITY

	"dry" 1981	"wet" 1982	"normal" 1987
Existing Roosevelt Bridge Channel	0.7 fps	1.3 fps	0.6 fps
Proposed Causeway	0.7 fps	1.3 fps	0.6 fps
Proposed Navigation Channel	0.7 fps	1.2 fps	0.5 fps

C, and E. Figure 7 is a re-creation of the discharges that occurred beneath the existing Roosevelt Bridge (location B). Figures 8 and 9 are simulations of the discharges in the channel beneath the proposed causeway (location B) and through the navigation channel (location E), respectively.

Comparison of Figures 7 and 8 indicates that little change would occur in discharges through the Roosevelt Bridge channel for existing and proposed conditions. Maximum seaward and landward discharges are on the order of 33,000 cfs. This translates into a mean velocity of 1.3 fps through the Roosevelt Bridge channel (location B). Close examination of Figures 7 and 8 indicate that a slightly greater volume of water passes beneath the existing Roosevelt Bridge than beneath the proposed causeway. Simulated maximum discharge through the navigation channel (Figure 9) is approximately 1600 cfs, which translates to a maximum mean velocity of less than 1.2 fps.

In summary, comparison of discharges indicates that construction of the causeway and tunnel with overlying navigation channel would result in only a minor alteration in the flow patterns of the estuary. Analysis of discharge through the navigation channel indicates a maximum flow of 1600 cfs and maximum mean velocity of 1.2 fps.

B. Salinity

The St. Lucie Estuary is an important habitat for marine species and salinity distribution is an important indicator of its suitability as a habitat. Model simulations provide an insight into the tidal-cycle variability in salinity concentration as influenced by hydrologic factors. Examination of salinity at locations throughout the estuary provide an indication of habitat conditions.

Figures 10 and 11 are time history graphs of simulations for salinity from the "dry" period (July 2 to October 1, 1981). These plots are representative of maximum anticipated concentrations associated with expected low flow conditions in the estuary. Figure 10 is a re-creation of historic salt concentrations that occurred in the estuary. Figure 11 is a simulation of the salt concentrations with the proposed navigation channel. Comparison of these figures shows no difference in salinity throughout the estuary for the period of simulation. The substantial decrease in salinity occurring just prior to the sixty day period in both low flow simulations is attributed to the significant rainfall that occurred in the St. Lucie Estuary drainage basins during September 1981.

Figures 12 and 13 are time history graphs of simulations for salinity from the "normal" period (April 1 to July 2, 1987). These plots are representative of concentrations associated with expected normal flow conditions in the estuary. Figure 12 is a re-creation of historic salt concentrations that occurred in the estuary. Figure 13 is a simulation of the salt concentrations with the new navigation channel. Comparison of these figures shows no difference in salinity throughout the estuary for the period of simulation. The substantial decreases in salinity occurring periodically in both 1987 simulations are the result of experimental supplemental releases at structure S-80 where pulsed discharges are implemented rather than a solitary massive flood control release.

The SLECM demonstrates that salinity in the estuary is very sensitive to fresh water inflows. However, comparison of simulations over the range of expected conditions indicates that the distribution of salinity throughout the St. Lucie Estuary will not change with the construction of the causeway and tunnel with an overlying navigation channel.

C. Tide

Tidal influence is the predominant force in the location of the transition from seaward to landward flow. Plotting water elevation in the vicinity of Roosevelt Bridge provides an insight into the tide cycle and the resulting variation in salinity distribution and discharge rates.

Figures 14 and 15 are time history graphs of simulations for tide from the "normal" period (April 1 to July 2, 1987). These plots are representative of simulated water elevations associated with expected normal flow conditions in the estuary. Figure 14 is a re-creation of historic water elevations that occurred in the estuary. Figure 15 is a simulation of the water elevations with the proposed navigation channel. Examination of these figures shows no difference in water elevations in the estuary for the period of simulation. Oscillations observed on the plots correlate to the diurnal tide and longer wave length / lower frequency cycle of the earth-moon rotation which causes the flood and ebb tides.

Examination of tidal elevations over the entire range of expected conditions at the four nodes in the vicinity of Roosevelt Bridge indicates that replacement of the drawbridge with a causeway and tunnel with an overlying navigation channel would not alter water level distribution throughout the estuary

D. Conclusion

The St. Lucie Estuary Computer Model (SLECM) is a far-field hydrodynamic / salinity computer model capable of simulating the St. Lucie Estuary under a variety of tidal and hydrologic conditions. The results of this preliminary investigation indicate that construction of the causeway and tunnel with an overlying navigation channel would minimally impact the flow pattern and not affect the salinity distributions of the St. Lucie Estuary. However, it is extremely important to recognize the limitations of the St. Lucie Estuary Computer Model (SLECM) as it was developed as an analytic tool for evaluating average cross-sectional conditions in the entire St. Lucie Estuary.

FIGURES

STUDY AREA

DISCHARGE

SALINITY

TIDE

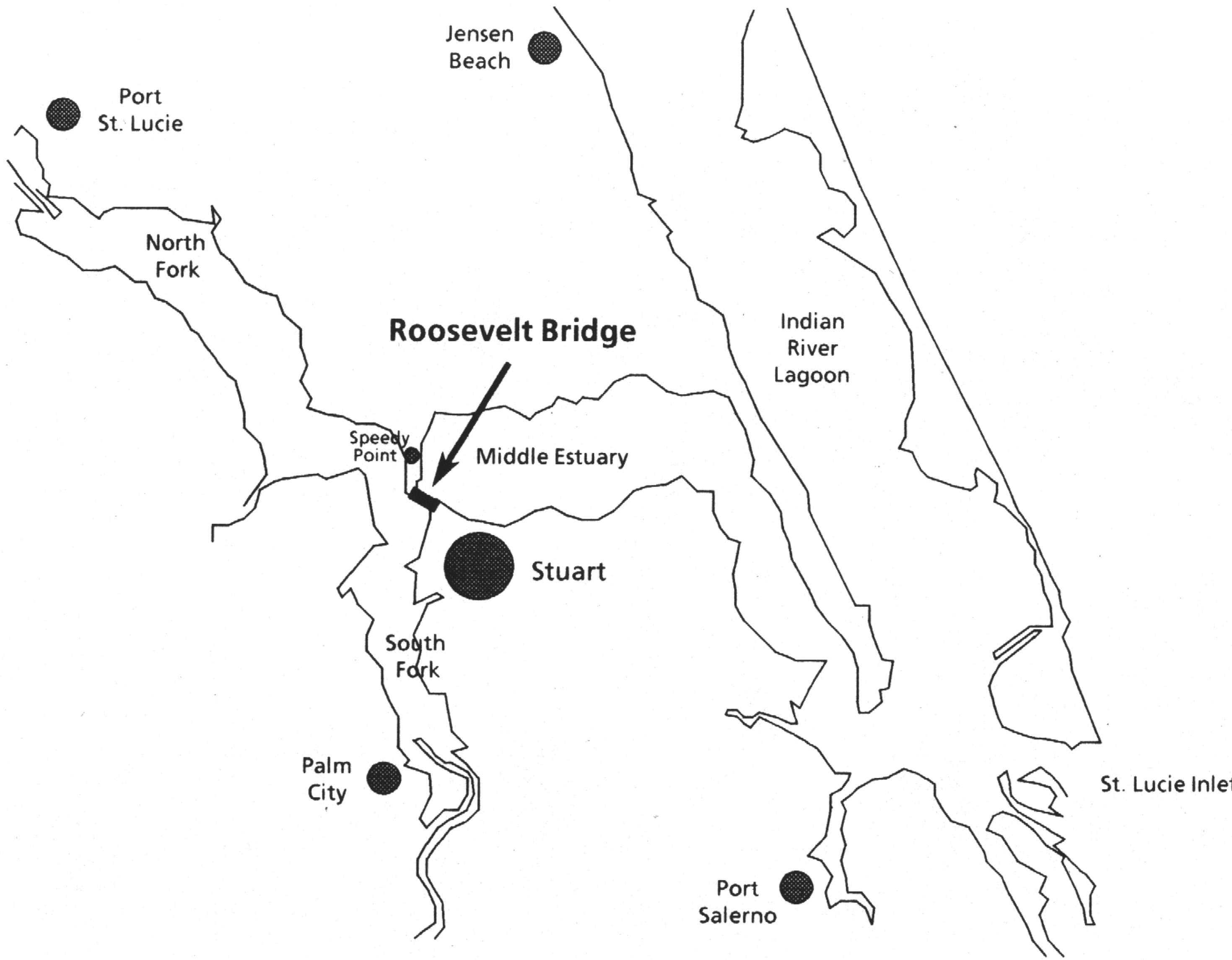

Figure 1. St. Lucie Estuary Study Area

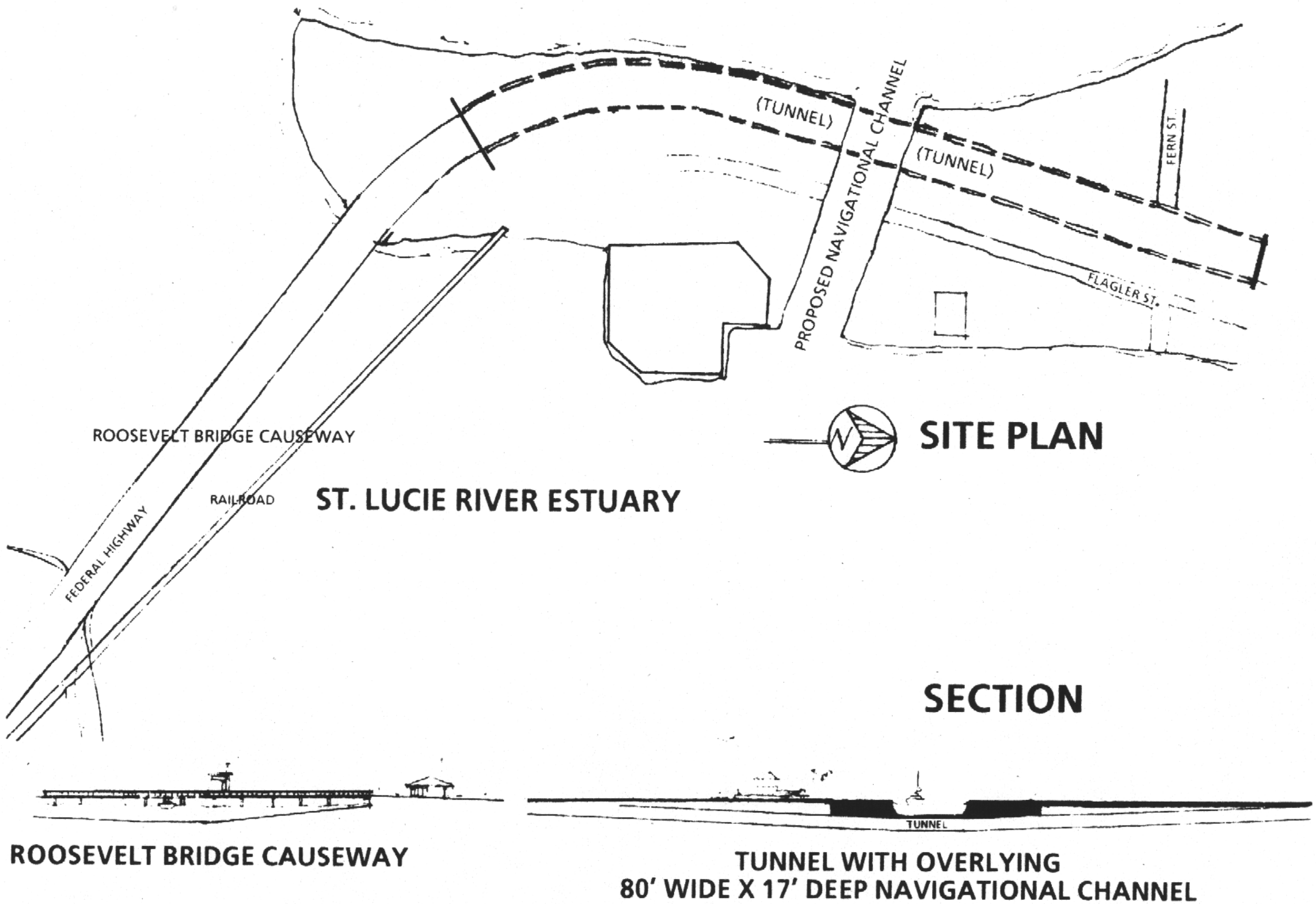

FIGURE 2. PROPOSED ROOSEVELT BRIDGE CAUSEWAY AND TUNNEL WITH OVERLYING NAVIGATION CHANNEL

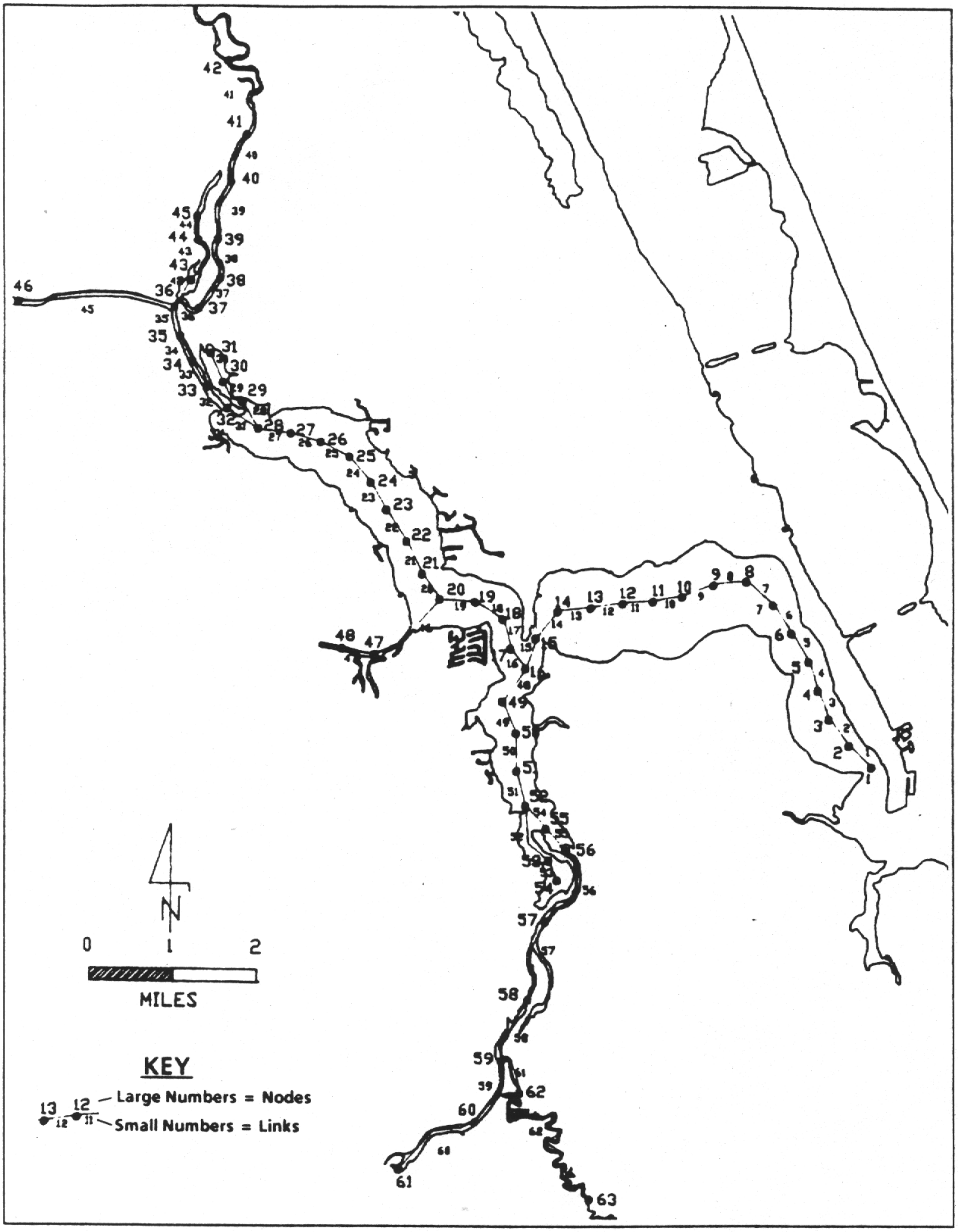

Figure 3 - St. Lucie Estuary Computer Model - Nodal Network

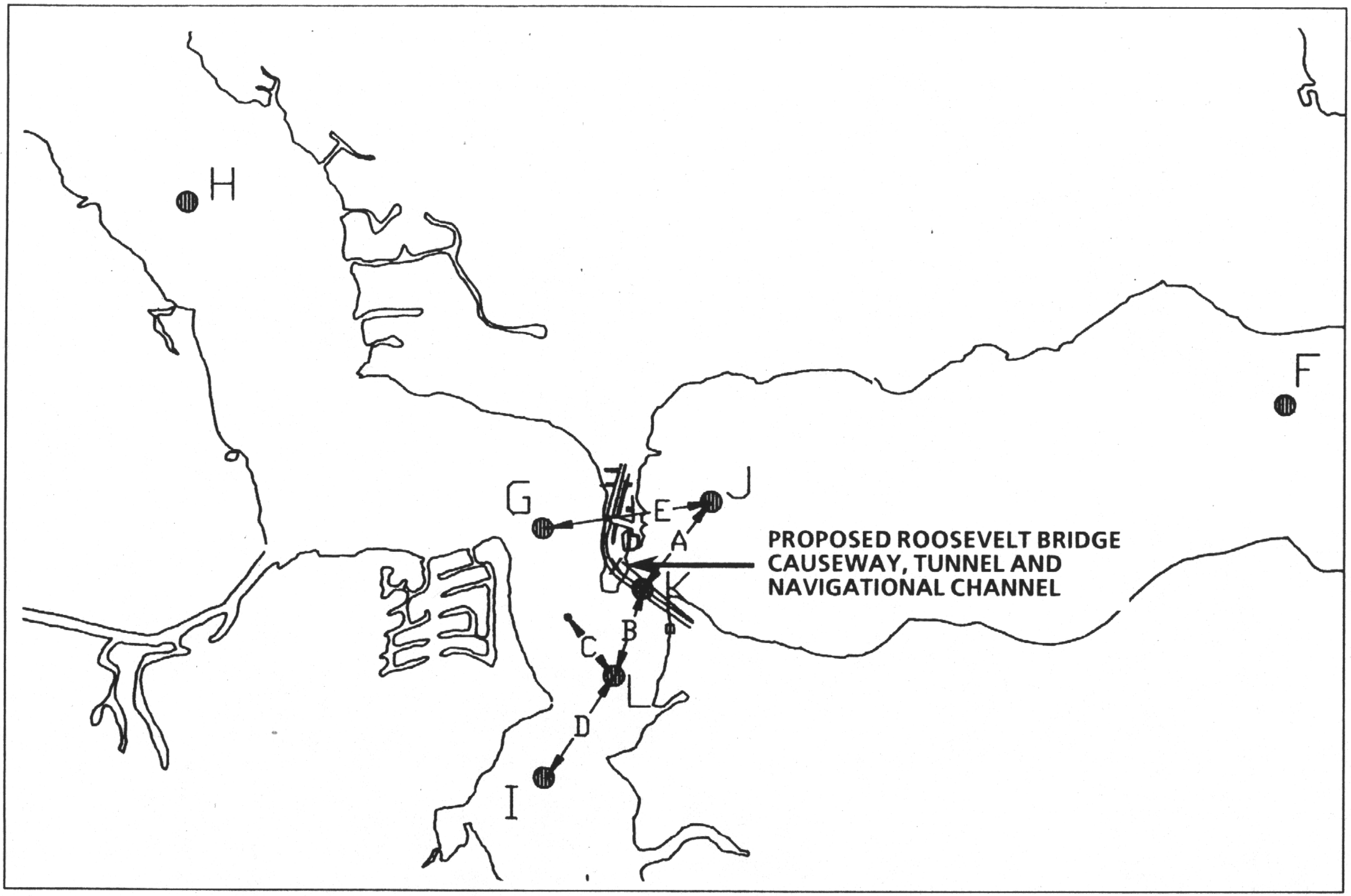

FIGURE 4. SITES SELECTED FOR EXAMINATION OF DISCHARGE, SALINITY AND TIDE

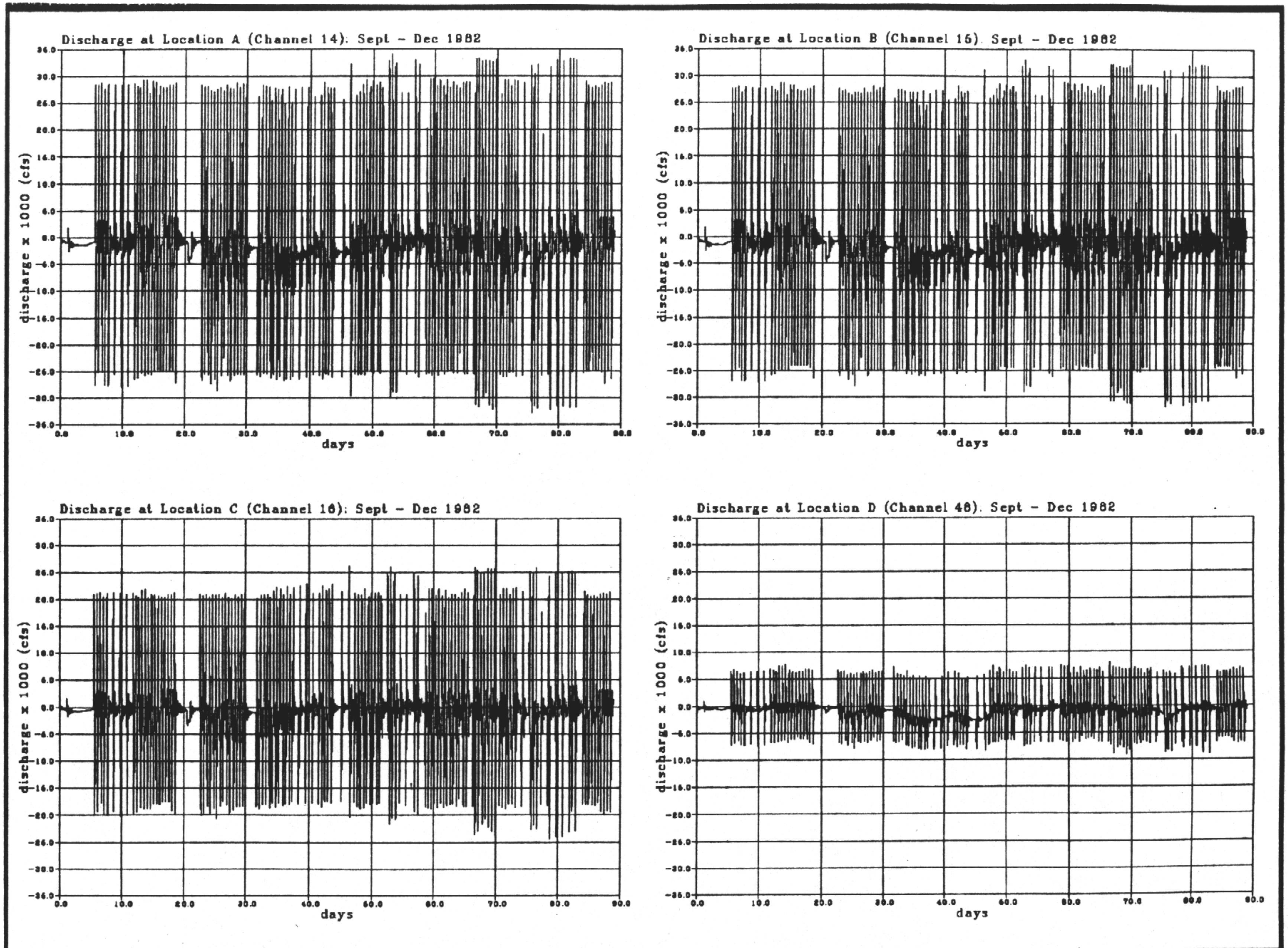

Figure 5 - Discharge September - December 1982 Historical Re-creation

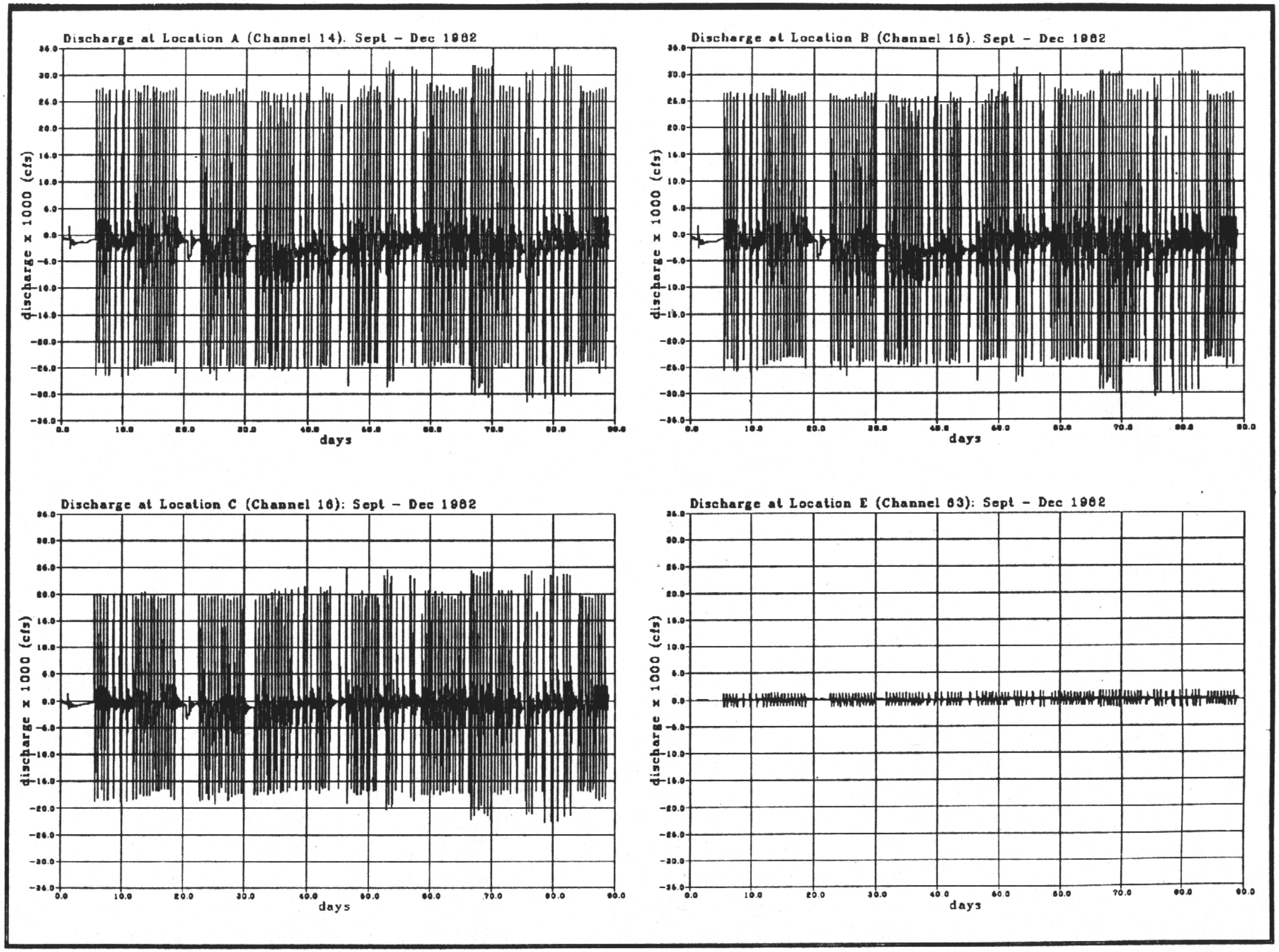

Figure 6 - Discharge September - December 1982 Historical Simulation

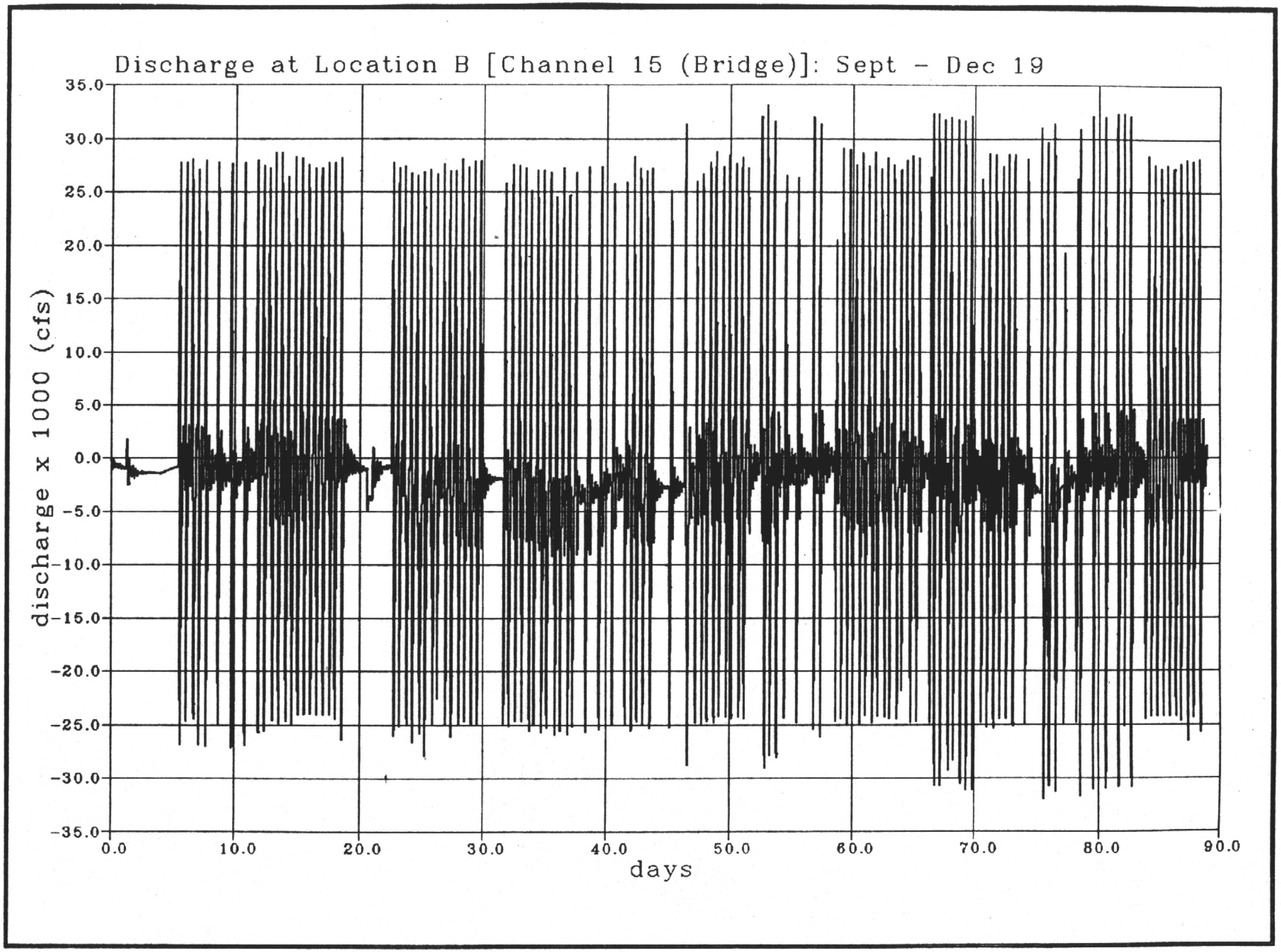

Figure 7 - Discharge [Bridge] September - December 1982 Historical Re-creation

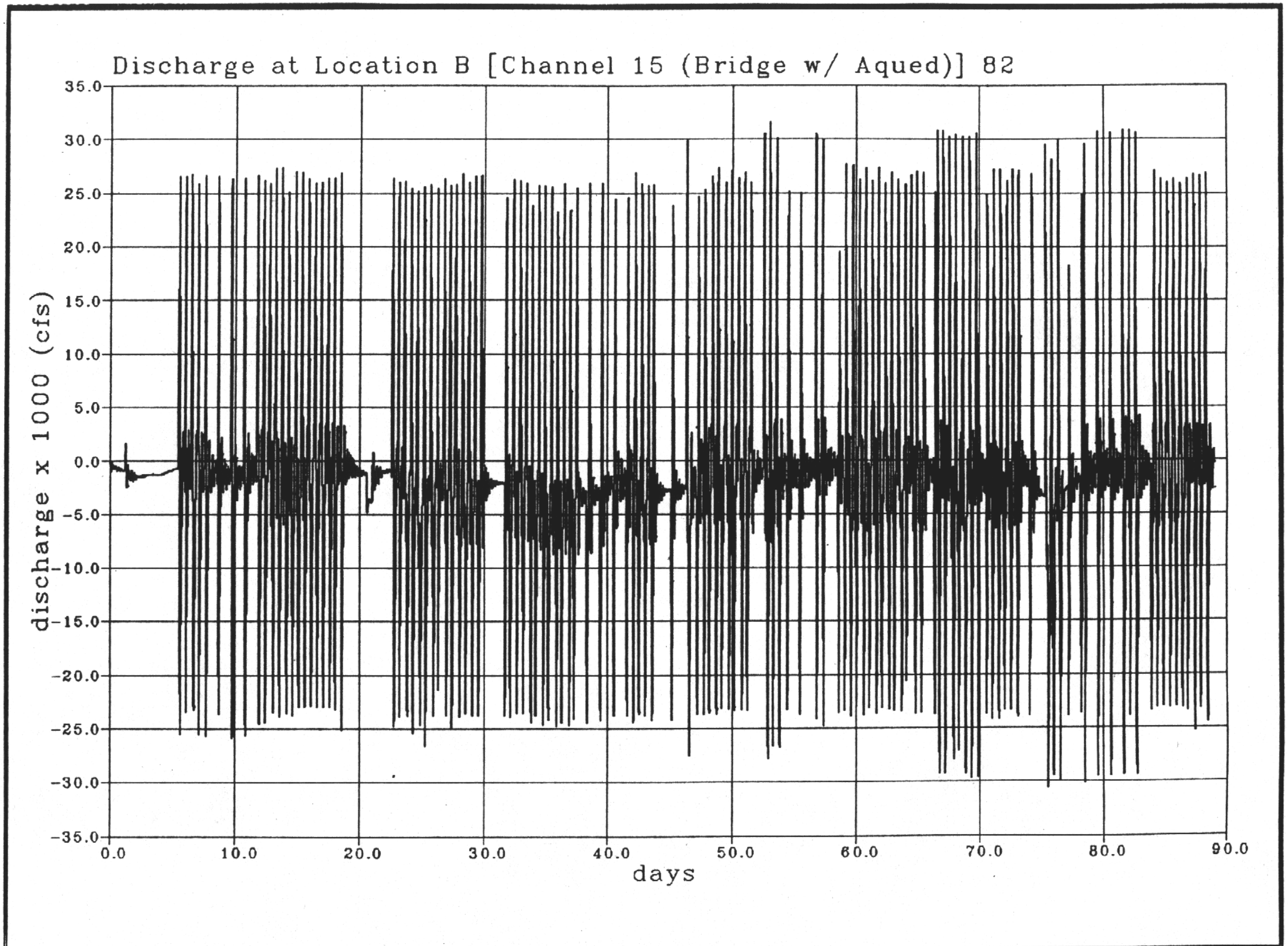

Figure 8 - Discharge [Bridge] September - December 1982 Historical Simulation

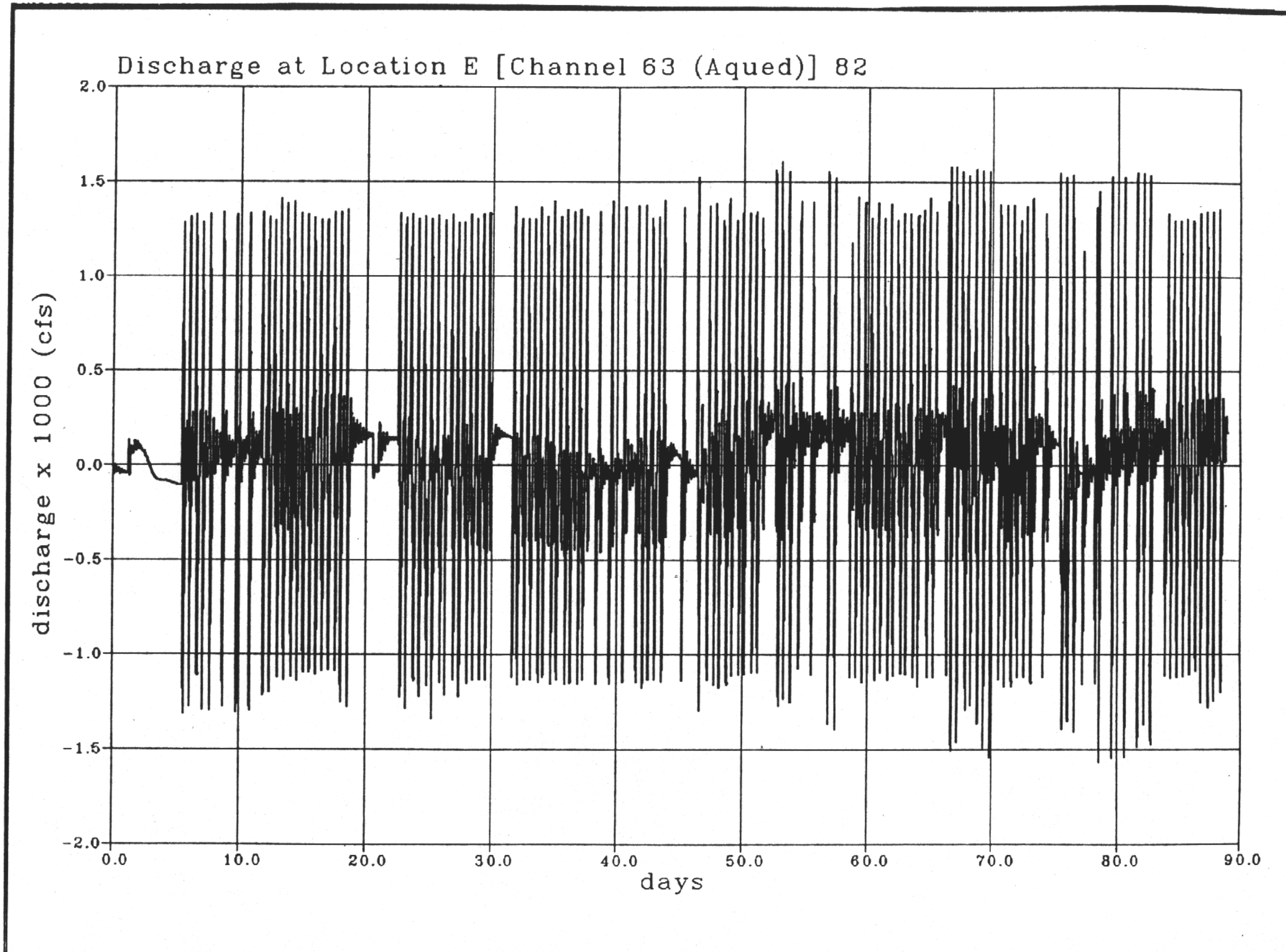

Figure 9 - Discharge [Aqueduct] September- December 1982 Historical Simulation

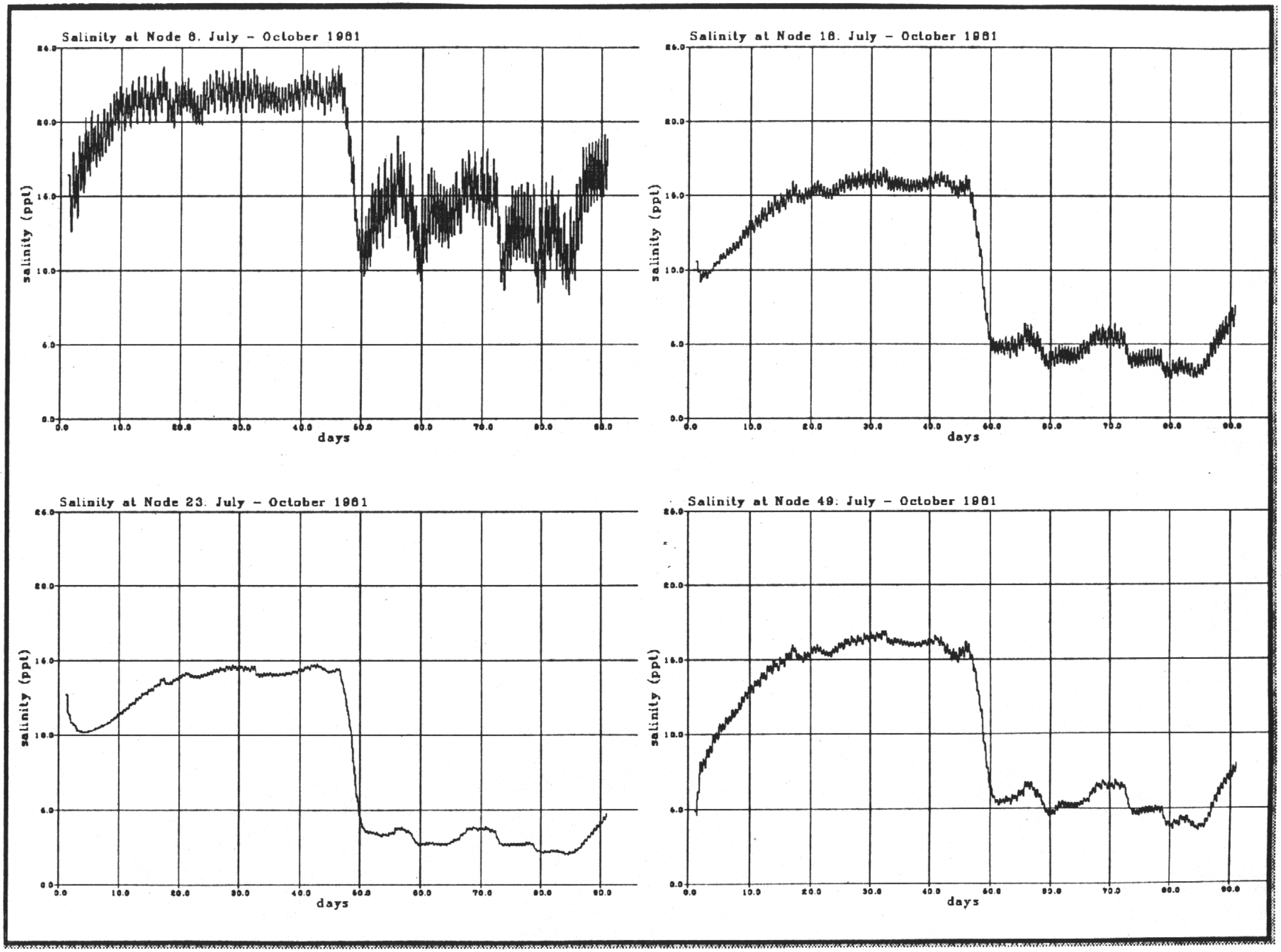

Figure 10 - Salinity July - October 1981 Historical Re-creation

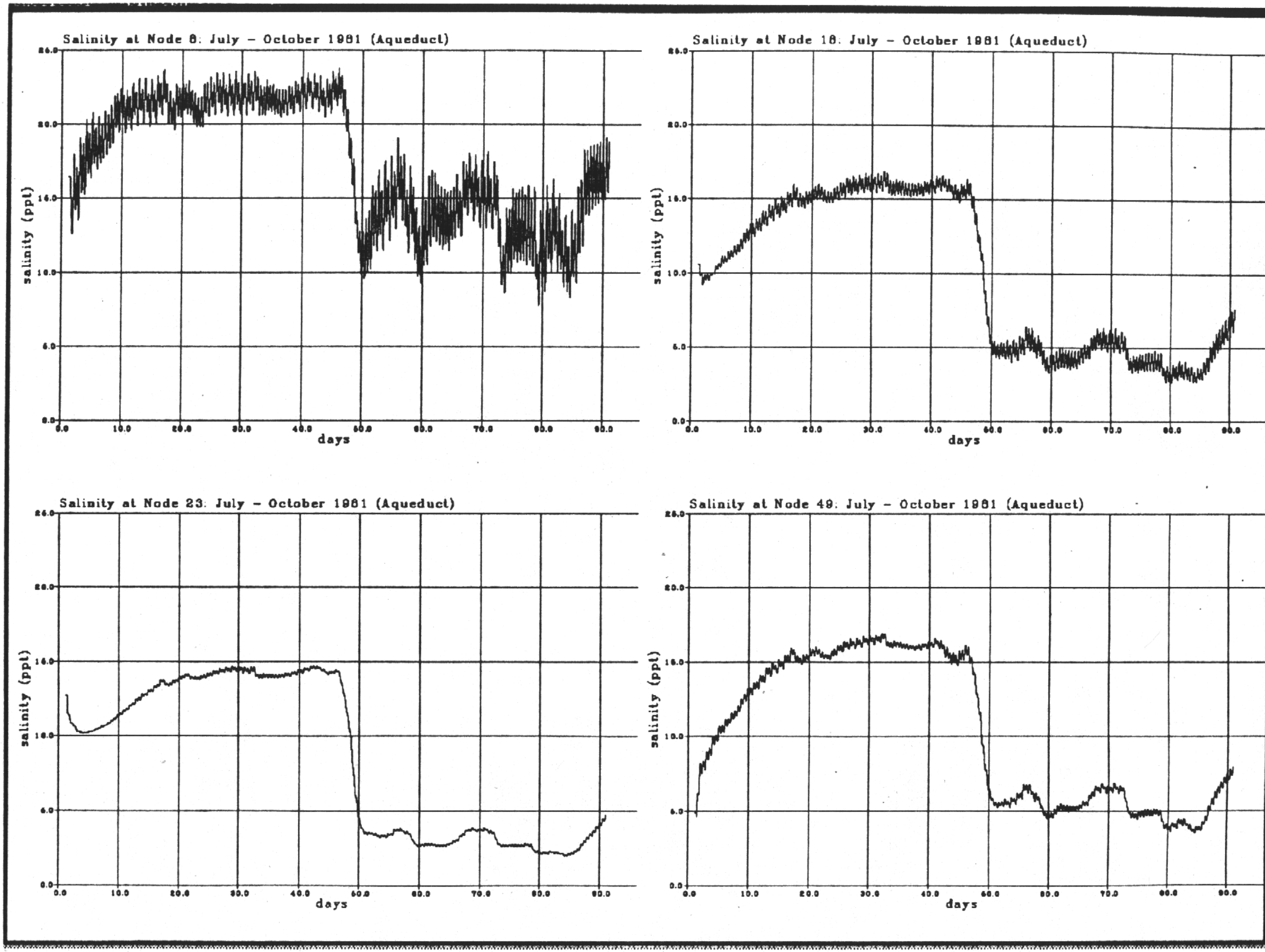

Figure 11 - Salinity July - October 1981 Historical Simulation

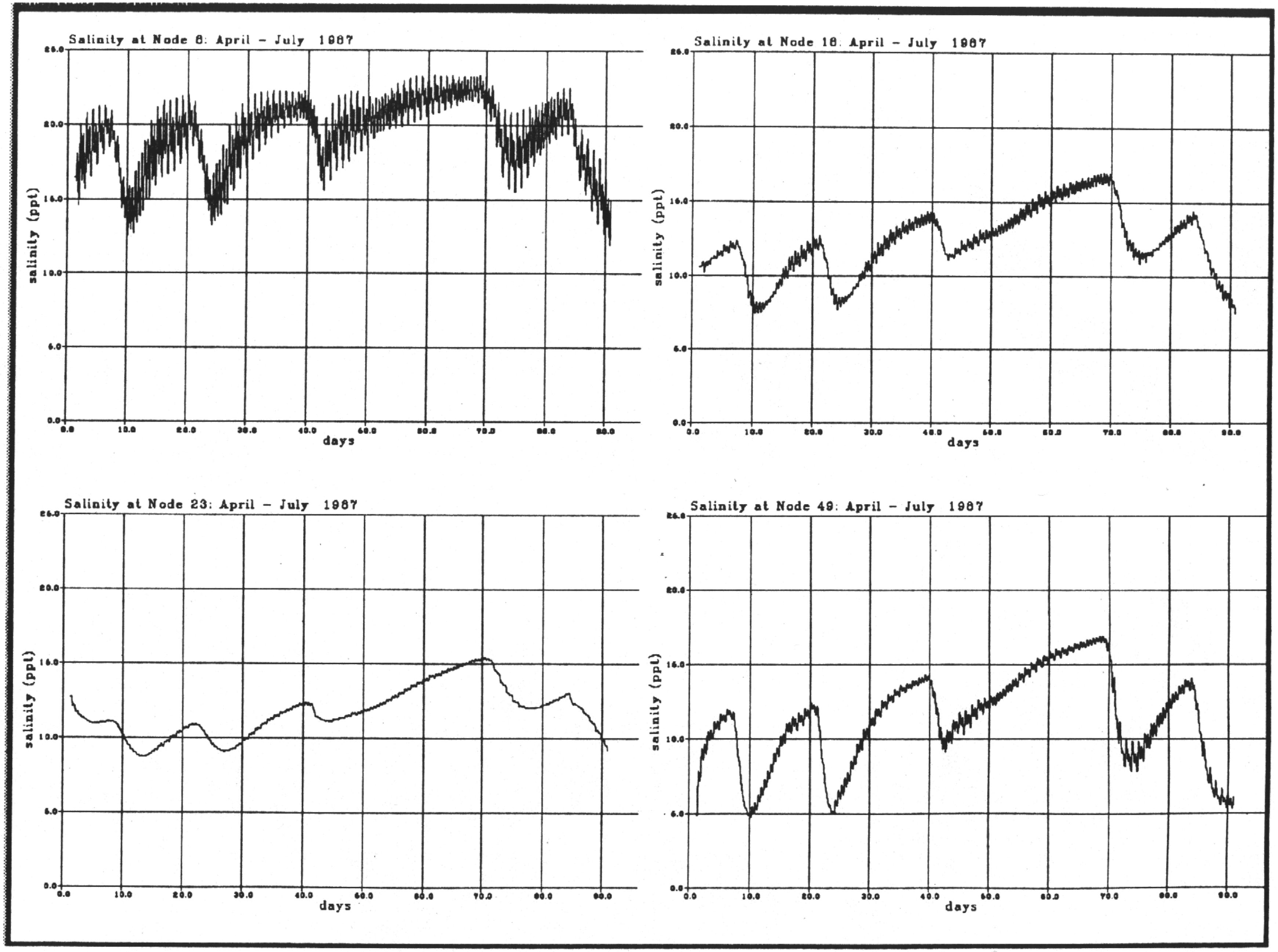

Figure 12 - Salinity April - July 1987 Historical Re-creation

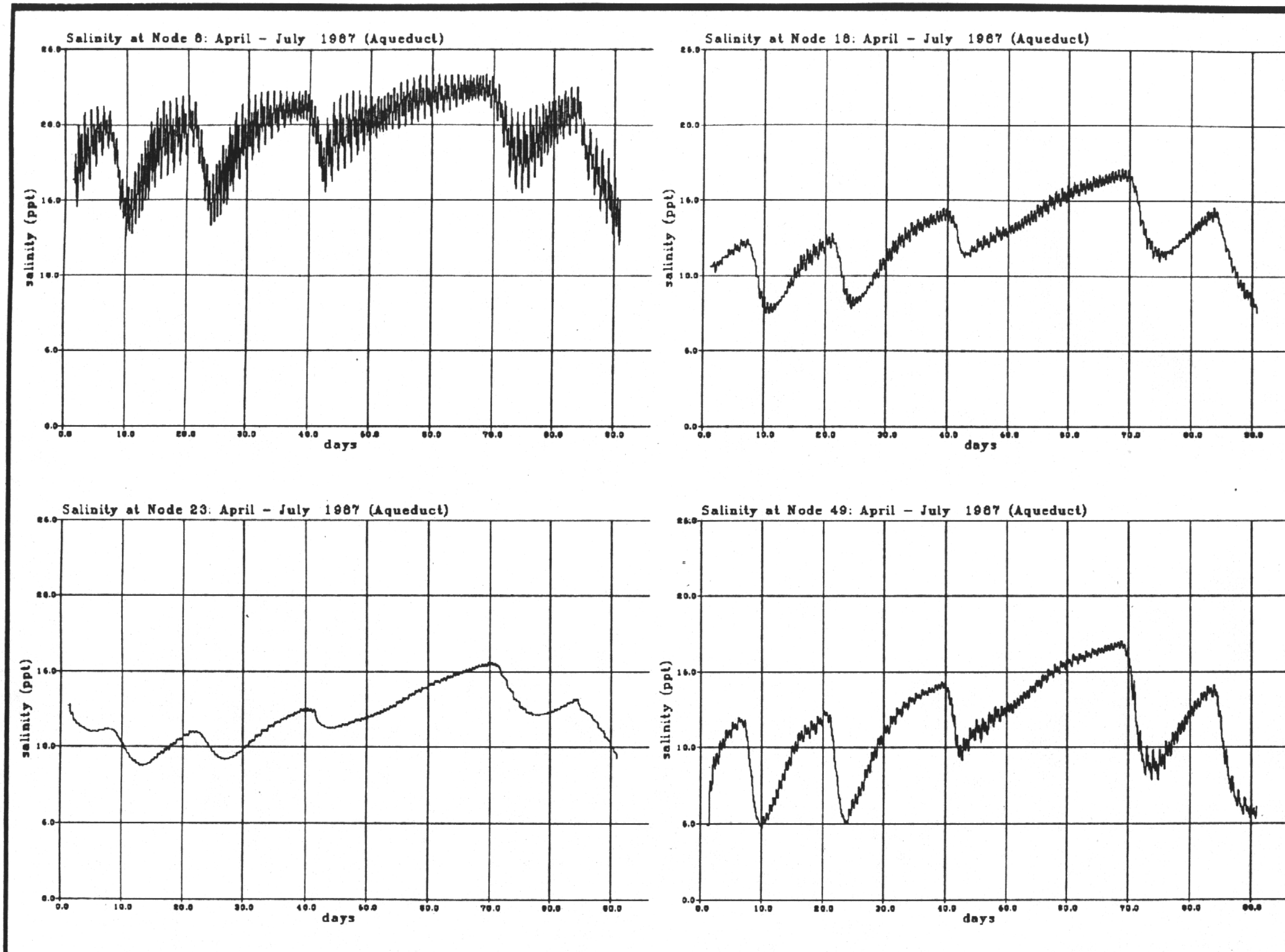

Figure 13 - Salinity April - July 1987 Historical Simulation

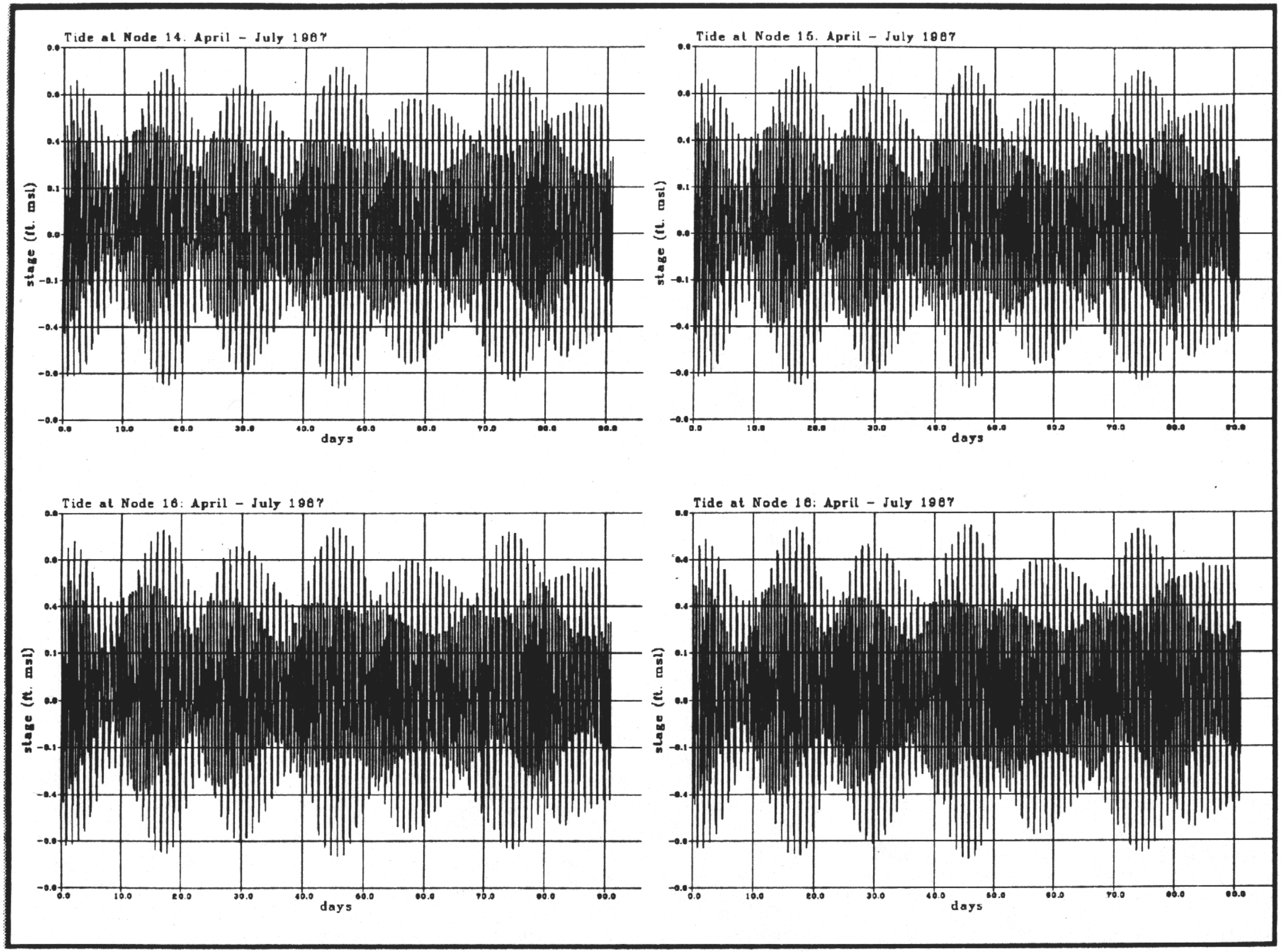

Figure 14 - Tide April - July 1987 Historical Re-creation

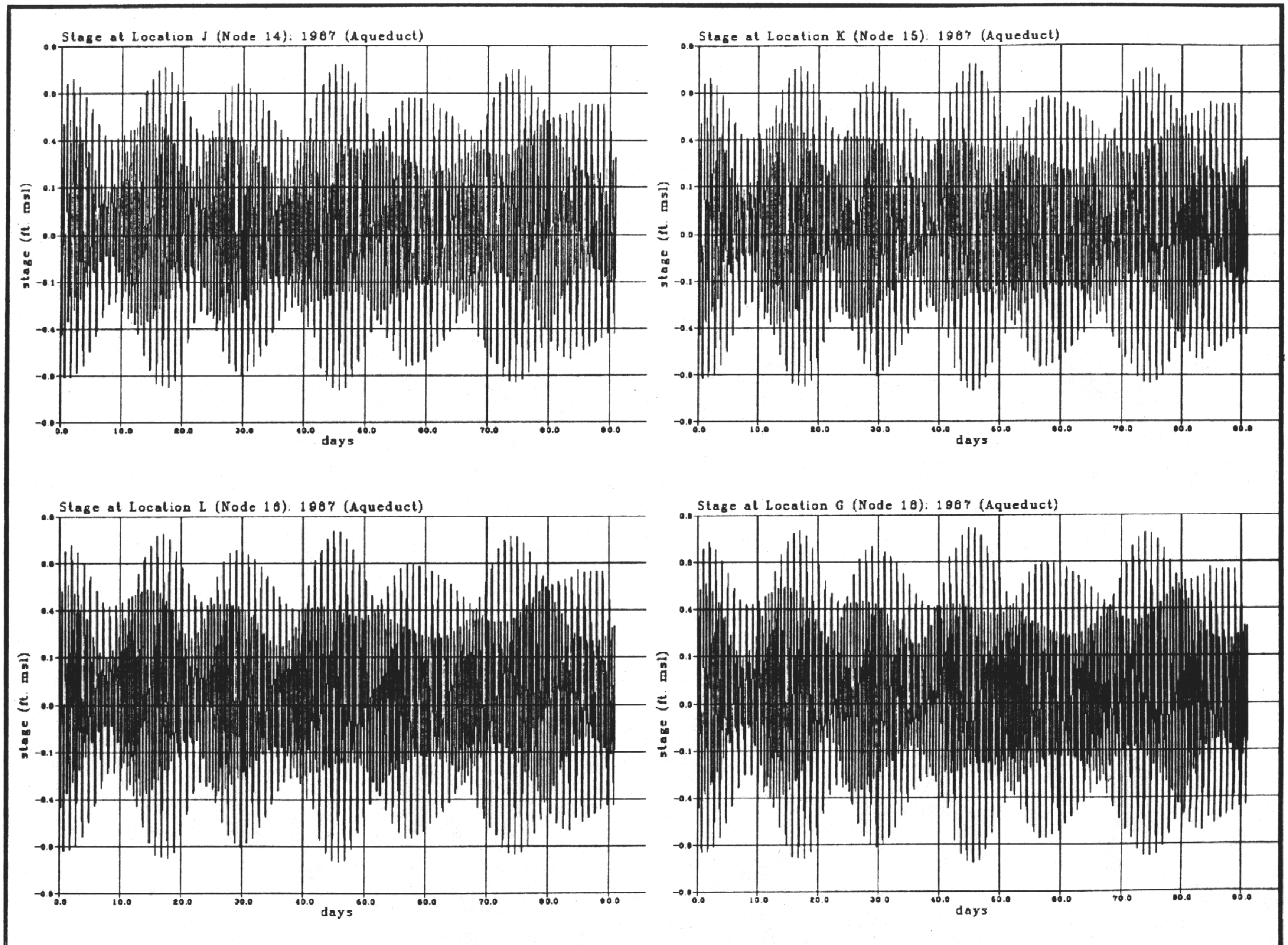

Figure 15 - Tide April - July 1987 Historical Simulation

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South Florida Water Management District

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EOF: MCA; P:89-17

March 15, 1989

The Honorable Frank A. Wacha
Chairman, Board of County Commissioners
Martin County
2401 S. E. Monterey Road
Stuart, FL 34996

Dear Chairman Wacha:

In response to your letter of March 2, the South Florida Water Management District does, indeed, have a hydraulic computer model for the St. Lucie Estuary based on the Bathymetry of the St. Lucie Estuary, 1986 (copy enclosed).

This agency would be pleased to assist Martin County in the evaluation of the aqueduct concept for the Roosevelt Bridge replacement. Modifications could be made to the existing estuary model to provide an evaluation of the impact on flows that an aqueduct may pose.

However, in order to model this scenario, we would need two things from either the County or your consulting engineer:

- a plan view of the proposed aqueduct showing the amount and lateral extent of encroachment into the existing channel; and
- a typical cross-sectional view providing existing and proposed transects.

Once this information is provided, we can adjust the model, run some scenarios and have a preliminary analysis back to you within four weeks.

Please contact Paul Millar (407/687-6310) for assistance during this process. We appreciate the opportunity to assist Martin County in this most interesting proposal.

Sincerely,

John R. Wodraska
Executive Director

JRW/PSM/js
Enclosure
c: J. D. York, SFWMD Governing Board Member
Paul Millar

bc: Jim Harvey
Kent Loftin
Charles Gove ✓